

Literature Survey on Thermophysical Properties of Refrigerants¹

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ABSTRACT

A compilation is given on available bibliographic references for the actual environmentally acceptable hydrofluorocarbon blends R404A, R407C, and R410A with emphasis on their thermophysical properties. These refrigerant blends are still under investigation and meant to replace the transitional hydrochlorofluorocarbon R22 and the azeotrope R502. In a second part reliable formulations to estimate thermophysical-property surfaces of some selected well investigated fluids used in refrigeration are recommended. The fluids water, air, carbon dioxide, ammonia, R134a, R152a, and R123 are subject of that part.

KEY WORDS: air; ammonia; carbon dioxide; bibliography; database; formulation; R123; R134a; R152a; R404A; R407C; R410A; refrigerants; thermophysical properties; water.

1. INTRODUCTION

The many applications in refrigeration require a variety of different substances with appropriate thermophysical characteristics. In addition, environment and climate relevant regulations – phaseout of chlorofluorocarbons (CFC) at the end of 1994 and scheduled phaseout of the transitional hydrochlorofluorocarbons (HCFC) at the end of this century due to their ozone depletion potentials (ODP) – lead researchers to identify new or already existent environmentally acceptable and safe refrigerants as replacements.

Substitutes for the CFC R12 and R11 were already successfully introduced in recent years. One of the present tasks is to find and investigate alternatives for the HCFC R22 and the azeotrope R502. The hydrofluorocarbon (HFC) blends R404A, R407C, and R410A are considered as replacements for these widely used refrigerants. Thus, one subject of this work is to compile bibliographic information on these new refrigerant blends, still under intensive investigation.

As there exists a great number of equations and correlations of different quality, in the second part some guidance is given for the evaluation of the most reliable and comprehensive formulations for thermophysical properties of water, air, carbon dioxide, ammonia, R134a, R152a, and R123.

This work is part of MIDAS¹ database project, initiated to compile and disseminate available information on thermophysical properties, i.e. thermodynamic and transport properties, of environmentally acceptable refrigerants and thus to satisfy

¹<http://www.fiz-karlsruhe.de/peu/midas/midas.html>

the increasing demand in science and industry for reliable, consistent, and easily accessible information.

2. BIBLIOGRAPHY FOR HFC BLENDS

Characteristics of the HFC blends R404A, R407C, and R410A as well as their constituents are listed in Table I together with the number of publications on thermophysical properties, filed in MIDAS database. As replacements for R22 and R502 these blends are quasi non-toxic, non-flammable with zero ozone depletion potential (ODP). They have, however, a significant global warming potential (GWP). Because of the small temperature glide, R404A and R410A may be regarded as near-azeotrope and azeotrope, respectively. The relatively high temperature glide of R407C is of disadvantage in case of leakage, and therefore may reduce its future application prospects. In Tables II – IV we compile the corresponding bibliographies. The properties considered are explained in Table V. Due to restricted space we cannot provide bibliographies on the pure components R32, R125, R134a, and R143a constituting these blends. We therefore refer to the internet address footnoted in the introduction.

3. RECOMMENDED FORMULATIONS

In Table VI we compile references on recommended formulations of thermophysical properties of well explored refrigerants. This is true at least for the thermodynamic properties. Substances considered here are the natural refrigerants wa-

ter, air, carbon dioxide and ammonia, the HFC R134a and R152a, as well as the transitional HCFC R123. We list references on the equation of state (EOS) and the transport properties viscosity and thermal conductivity. We only consider consistent formulations based on comprehensive evaluations, covering a large range of temperature and pressure or density, respectively, and valid in the entire fluid state of technical interest. Further reliable correlations only describing parts of the property surface are not considered here. From the EOS formulations other thermodynamic properties can be derived. Due to the precise measurements on which EOS formulations are based, the accuracy of these equations is higher than that of transport-property equations by an order of magnitude. Furthermore, although representing the most reliable formulations available at present, particularly the expressions for the transport properties of R134a, the viscosity of R123, and the thermal conductivity of ammonia need further improvement due to scattering and lack of experimental data.

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Table I. Actual HFC Blends and Their Components

Name	Composition ^a	TG ^b	Formula	<i>M</i> ^c	<i>T_b</i> ^d	<i>T_c</i> ^e	<i>P_c</i> ^f	Pub ^g
R125 (44%)								
R404A	R143a (52%)	0.7	C ₆ H ₆ F ₁₂	97.60	-46.5	72.1	3.73	19
R134a (4%)								
R32 (23%)								
R407C	R125 (25%)	7.4	C ₅ H ₅ F ₁₁	86.20	-43.6	86.7	4.62	23
R134a (52%)								
R410A	R32 (50%)	<0.1	C ₃ H ₃ F ₇	72.56	-50.5	72.5	4.96	20
	R125 (50%)							
R32								
			CH ₂ F ₂	52.02	-51.7	78.2	5.80	162
R125								
			C ₂ HF ₅	120.02	-48.1	66.3	3.63	121
R134a								
			C ₂ H ₂ F ₄	102.03	-26.1	101.1	4.07	331
R143a								
			C ₂ H ₃ F ₃	84.04	-47.4	73.6	3.83	81

^amass %; ^bTG: temperature glide in °C; ^c*M*: molecular mass in kg·kmol⁻¹; ^d*T_b*: normal boiling point temperature in °C; ^e*T_c*: critical temperature in °C; ^f*P_c*: critical pressure in MPa; ^gPub: number of publications, filed in MIDAS database.

Table II. Bibliography for R404A

First Author	Year	Properties	Ref. No.
<i>Ahnefeld G.</i>	1996	use	[1]
<i>Benade W.</i>	1994	dyn	[2]
<i>Bouchot C.</i>	1995	pvt,vle	[3]
<i>Geller V.Z.</i>	1994	dv,tc	[5]
<i>Guenther D.</i>	1996	c_p	[6],[7],[8]
<i>Heide R.</i>	1996	dv,sig	[9]
<i>Heide R.</i>	1996	dv,vol	[10]
<i>Hoffmann N.</i>	1996	tc	[12]
<i>Kruse H.</i>	1996	dyn,env	[16]
<i>Nagel M.</i>	1994	eos,ps,vle	[19]
<i>Nagel M.</i>	1996	eos,ps,pvt,vle	[21]
<i>Schwennesen K.</i>	1993	dyn,env,use	[24]
<i>Spindler K.</i>	1996,97	tc	[25],[26]
<i>Spindler K.</i>	1996	use	[27]
<i>Stenzel B.</i>	1994	env	[28]
<i>Wilms M.</i>	1993	dyn,env,use	[31]

Table III. Bibliography for R407C

First Author	Year	Properties	Ref. No.
<i>Ahnefeld G.</i>	1996	use	[1]
<i>Benade W.</i>	1994	dyn	[2]
<i>Guenther D.</i>	1996	c_p	[6],[7],[8]
<i>Heide R.</i>	1996	dv,sig	[9]
<i>Heide R.</i>	1996	dv,vol	[10]
<i>Hoffmann N.</i>	1996	tc	[12]
<i>Kiyoura H.</i>	1996	dyn,pvt	[14]
<i>Kleemiss M.</i>	1994	eos,vle	[15]
<i>Kruse H.</i>	1996	dyn,env	[16]
<i>Morrison J.D.</i>	1995	dyn,eos	[17]
<i>Morrison J.D.</i>	1996	use,vle	[18]
<i>Nagel M.</i>	1994	eos,ps,vle	[19]
<i>Nagel M.</i>	1995	eos,pvt,vle	[20]
<i>Oguchi K.</i>	1995	pvt	[22]
<i>Schwennesen K.</i>	1993	dyn,env,use	[24]
<i>Spindler K.</i>	1996,97	tc	[25],[26]
<i>Spindler K.</i>	1996	use	[27]
<i>Stenzel B.</i>	1994	env	[28]
<i>Widiyatmo J. V.</i>	1995	dyn	[29]
<i>Wilms M.</i>	1993	dyn,env,use	[31]

Table IV. Bibliography for R410A

First Author	Year	Properties	Ref. No.
<i>Benade W.</i>	1994	dyn	[2]
<i>Doering R.</i>	1995	dyn,eos,ps,vol	[4]
<i>Guenther D.</i>	1996	c_p	[6],[7],[8]
<i>Heide R.</i>	1996	dv,sig	[9]
<i>Hewitt N.J.</i>	1996	dyn,eos,use	[11]
<i>Hoffmann N.</i>	1996	tc	[12]
<i>Kim D.S.</i>	1995	tc	[13]
<i>Kleemiss M.</i>	1994	eos,vle	[15]
<i>Kruse H.</i>	1996	dyn,env	[16]
<i>Morrison J.D.</i>	1995	dyn,eos	[17]
<i>Nagel M.</i>	1994	eos,ps,vle	[19]
<i>Nagel M.</i>	1995	eos,pvt,vle	[20]
<i>Sato T.</i>	1996	pvt	[23]
<i>Spindler K.</i>	1996,97	tc	[25],[26]
<i>Spindler K.</i>	1996	use	[27]
<i>Widiatmo J.V.</i>	1994	dyn	[30]
<i>Zhang H.-L.</i>	1996	dyn,eos,pvt	[32]

Table V. Properties in Tables II – IV

Symbol	Property/Topic
c_p	isobaric heat capacity
dyn	misc. thermodynamic properties
dv	dynamic viscosity
env	environmental properties/aspects
eos	equation of state
ps	vapor pressure
pvt	p,v,T properties
sig	surface tension
tc	thermal conductivity
use	use, application
vle	vapor-liquid equilibrium
vol	specific volume, density

Table VI. Recommended Formulations

Substance	Equation of State	Viscosity	Thermal Conductivity
Water	<i>Haar</i> [36, 37]	<i>Haar</i> [36, 37]	<i>Haar</i> [36, 37]
Air	<i>Jacobsen</i> [38]	<i>Kadoya</i> [39]	<i>Stephan</i> [45], <i>Kadoya</i> [39]
CO ₂	<i>Span</i> [44]	<i>Fenghour</i> [35]	<i>Vesovic</i> [50]
Ammonia	<i>Tillner-Roth</i> [47]	<i>Fenghour</i> [34]	<i>Krauss</i> [42] ^a
R134a	<i>Tillner-Roth</i> [49]	<i>Krauss</i> [40]	<i>Krauss</i> [40]
R123	<i>Younglove</i> [51], <i>Baehr</i> [33]	<i>Tanaka</i> [46]	<i>Laesecke</i> [43]
R152a	<i>Tillner-Roth</i> [48]	<i>Krauss</i> [41]	<i>Krauss</i> [41]

^atables.